Three-Dimensional Reconstruction of the Temporal Bone

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Study of the complex anatomy and pathology of the temporal bone has traditionally used microscopy which permits analysis in only two dimensions. Recent advances in bioimaging technology have permitted visualization and reconstruction of computed tomography images in three dimensions. We have developed a technique that applies this technology in the imaging and reconstruction of human temporal bones. Data taken from serial histologic sections of the temporal bone are entered into a computer. The sections are edited and, through the use of specially developed software, a realistic three-dimensional reconstruction is produced. The reconstructed image can be rotated along any of three axes, and structures within the temporal bone can be isolated for more detailed analysis. Applications for the study of pathologic conditions of the temporal bone will be discussed.

INTRODUCTION

The study of temporal bone histopathology has provided great insights into the anatomy and pathology of the temporal bone. The shortcoming of histologic examination lies in the fact that a three-dimensional structure is being viewed in only two dimensions. Microscopic dissection has provided valuable information about three-dimensional anatomic relationships within the temporal bone. However, dissection is a destructive study method that can preclude future examination of the dissected region and might be difficult to reproduce.

Recent advances in bioimaging technology have been linked to progress in computer science. Improved computer processing and storage in combination with newly developed software have enabled three-dimensional images to be generated from two-dimensional radiographic studies.[1]

Recent publications [2-7] have highlighted the potential for three-dimensional study of the structures within the temporal bone from histologic sections. The utricle and saccule,[2] eustachian tube,[3] endolymphatic sac,[4,5] and temporomandibular joint[6] have all been studied in three dimensions. The entire temporal bone was studied in three dimensions by Harada, *et al.*[7] In each of these studies, a personal computer was used in combination with individually developed or commercially available software. In the current study, a mid-sized computer was combined with a powerful, three-dimensional software pro-

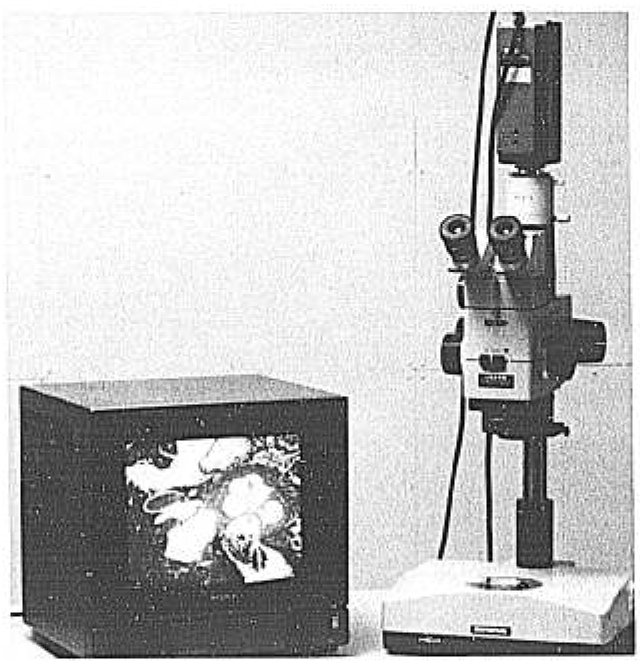

Fig. 1. Video camera attached to dissecting microscope with temporal bone visualized on television screen.

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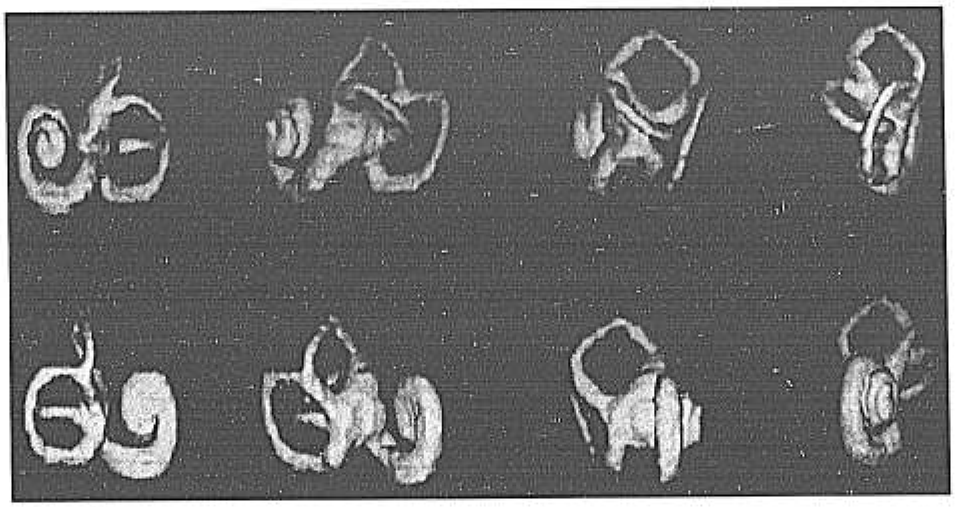

Figure 2

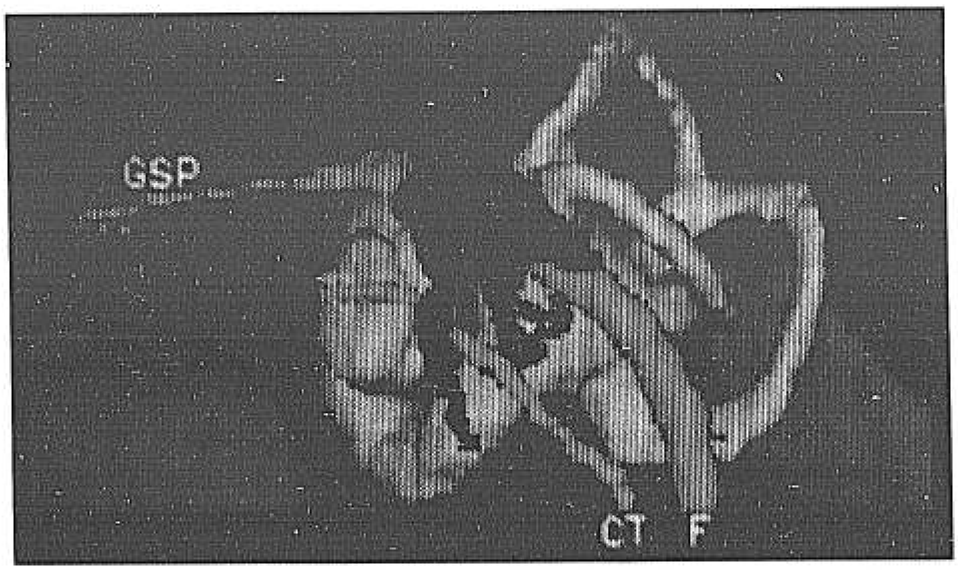

Figure 3

Figs. 2–5. Bony labyrinth (cochlea and semicircular canals) represented in white; carotid artery is red; ossicles are brown; cochlear aqueduct is green; endolymphatic sac is light blue; facial, chorda tympani, and greater superficial petrosal nerves are yellow. See "Results" for further description.

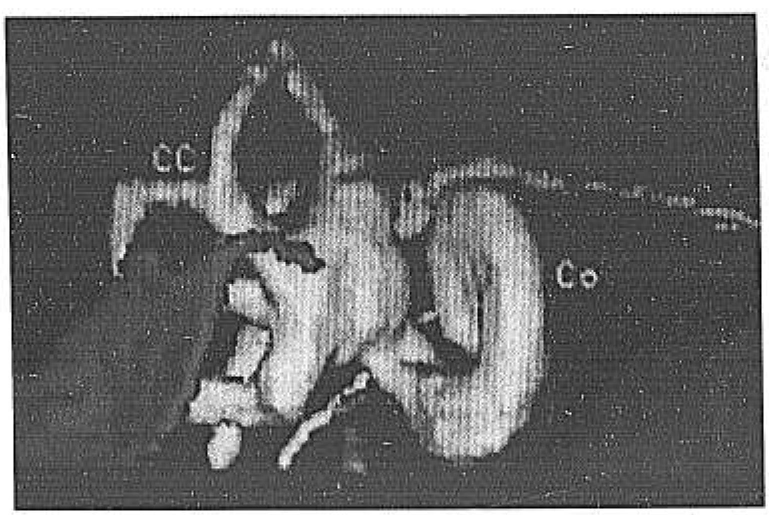

Figure 4

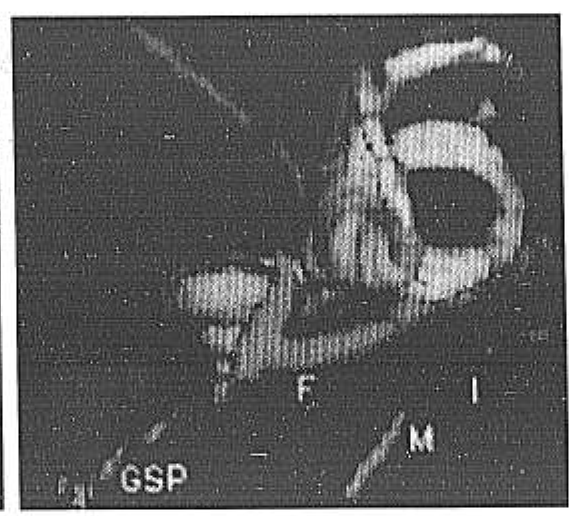

Figure 5

gram[8,9] to allow a detailed three-dimensional image of the temporal bone to be generated and studied.

MATERIAL AND METHODS

The temporal bones of a 25-year-old man were removed in a standard fashion at the time of autopsy. The patient had died 22 hours previously as a result of complications from malignant lymphoma. The patient's hearing was described as normal in the history; however, no audiogram was available for review. The temporal bones were placed in fixative and subsequently decalcified and embedded in celloidin. The left temporal bone was sectioned horizontally to the level of the superior semicircular canal for orientation of the specimen. Four holes (fiduciaries) were drilled in the temporal bone perpendicular to the plane of sectioning. The temporal bone was then sectioned every 20μ and every fifth section was mounted and stained with hematoxylin and eosin. Microscopic examination of the temporal bone revealed no evidence of a pathological condition in the middle or inner ear. A total of 106 slides were available for study.

The slides were visualized by attaching a video camera to a dissecting microscope (Fig. 1). The image was viewed on a television screen at 3.75 × magnification where the fiduciaries were used to align sequential sections. Each section was digitized and transferred to a workstation (68020 processor with 8 megabytes of random access memory). The sections were then stored within the memory of the computer. In addition, a ruler was similarly digitized to assure accurate measurements within the temporal bone.

Each section was edited by outlining a single histologic structure on the computer screen with the cursor. Sequential sections were edited for the structure in a similar manner. Editing was repeated in the coronal and sagittal planes and a file was created for the structure. The procedure was repeated to create ten separate files representing ten structures (Table I) from the temporal bone. This process is known as segmentation and allows individual structures to be isolated and manipulated.

A three-dimensional image of each of the structures was then reconstructed. The edges of the reconstructed structures were smoothed by low-pass filtering. The computer-generated three-dimensional images were examined jointly and individually in a multiplanar fashion. Each histologic structure was assigned a different color.

RESULTS

The three-dimensional image was realistic and accurate with respect to anatomic structural relationships. The surface of each structure was smooth and the structures were graphically represented. The image was generated as a shaded surface display which displayed structures closer to the viewer as lighter and objects further away as darker.

The bony labyrinth is shown from eight different views in Figure 2. Each of the images has been rotated 45 degrees with respect to the preceding image. Note the two and one half turns of the cochlea, the vestibule, and the semicircular canals. The right angle formed between the lateral and posterior semicircular canals can be seen in the third image from the left on the top row.

Figure 3 shows all of the temporal bone structures from a posterolateral view. The internal carotid artery (red) is seen adjacent to the basal turn of the cochlea. The malleus, incus, and stapes are surrounded by the nerves of the middle ear. The chorda tympani (CT) nerve is seen coursing between the manubrium of the malleus and the long process of the incus. The facial nerve (F) can be seen arching over the stapes near the external (mastoid) genu. The greater superficial petrosal nerve (GSP) is seen extending anteriorly over the carotid artery. The endolymphatic sac (light blue) lies next to the posterior semicircular canal.

TABLE I.
Histologic Structures Used in 3-D Reconstruction.

1. Endolymphatic duct and sac	6. Bony labyrinth
2. Coclear aqueduct	7. Internal carotid artery
3. Facial nerve	8. Incus
4. Greater superficial petrosal nerve	9. Malleus
5. Chorda tympani nerve	10. Stapes

The temporal bone is seen from an anteromedial view in Figure 4. The endolymphatic sac (light blue) can be seen with its duct emptying into the vestibule near the common crus (CC). The common crus is formed by the union of the superior and posterior semicircular canals. The basal turn of the cochlea (Co) is easily visualized from this view.

Figure 5 shows the structures of the temporal bone superiorly from the middle cranial fossa. The facial nerve (F) is seen with the greater superficial petrosal nerve (GSP) extending anteriorly from the geniculate ganglion. The cochlear aqueduct (light green) is visible coursing toward the basal turn of the cochlea. The head of the malleus (M) along with the body and short process of the incus (I) are also seen from this view.

DISCUSSION

The ability to obtain precise measurements and volumes makes three-dimensional reconstruction applicable to a wide variety of anatomic studies of both normal and pathologic temporal bones. Takagi and Sando[2] have shown that physiologic data regarding the position of the utricle and saccule within the vestibule can be obtained from three-dimensional images. In addition, the ability to examine the temporal bone from any angle might allow the technique to be used to design and study new surgical approaches.

Potential error sources in the present study include imperfect alignment of sequential sections and compression artifact from sectioning. The use of fiduciaries has greatly reduced alignment difficulties, and experienced laboratory personnel help minimize compression artifact from processing and sectioning the temporal bone.

A computer-generated three-dimensional study of the temporal bone offers many potential advantages. The image can be rotated, manipulated, and measured with a high degree of accuracy. A three-dimensional understanding of temporal bone anatomy may be imparted to medical students and residents with greater clarity and understanding.

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BIBLIOGRAPHY

1. Robb, R.A.: *Three-Dimensional Biomedical Imaging.* (Vol. 1). CRC Press, Inc., Boca Raton, Fla., pp. 107–164, 1985.
2. Takagi, A. and Sando, I.: Computer-Aided Three-Dimensional Reconstruction and Measurement of the Vestibular End-Organs. *Otolaryngol. Head Neck Surg.*, 88:195–202, 1988.
3. Mori, K., Naito, Y., Hirono, Y., *et al.*: Three-Dimensional Computer Graphics of the Eustachian Tube. *Am. J. Otolaryngol.*, 8:211–213, 1987.
4. Linthicum, F.H. and Galey, F.R.: Computer-Aided Reconstruction of the Endolymphatic Sac. *Acta Otolaryngol.*, 91:423–429, 1981.
5. Antunez, J.M., Galey, F.R., Linthicum, F.H., *et al.* Computer-aided and Graphic Reconstruction of the Human Endolymphatic Duct and Sac. *Ann. Otol. Rhinol. Laryngol.*, 89 (Suppl. 76):23–32, 1980.
6. Roberts, D., Pettigrew, J., Udupa, J., *et al.*: Three-Dimensional Imaging and Display of the Temporomandibular Joint. *Oral Surg.*, 58:461–474, 1984.
7. Harada, T., Ishii, S. and Tayama, N.: Three-dimensional Reconstruction of the Temporal Bone From Histological Sections. *Arch. Otolaryngol. Head Neck Surg.*, 114:1139–1142, 1988.
8. Robb, R.A.: Multidimensional Biomedical Image Display and Analysis in the Biotechnology Computer Resource at the Mayo Clinic. *Machine Vision and Application,* 1:75–96, 1988.
9. Robb, R.A. and Babillot, C.: Interactive 3-D Image Display and Analysis. *Proc. S.P.I.E.*, 939:713–202, 1988.

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